

United States
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Geological Survey

Water-supply investigation of Fort Defiance area,
Navajo Indian Reservation, Apache County, Arizona

By

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With a section on

Quality of water

By

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Tucson, Arizona

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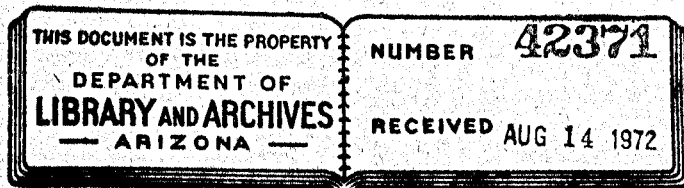
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ABSTRACT

1

The ground-water resources of the Fort Defiance area were investigated by the Geological Survey in 1948. Fort Defiance is on the Navajo Indian Reservation, in the east-central part of Apache County, Arizona.

The geologic section exposed in the area ranges from pre-Cambrian quartzite upward through Permian, Triassic, Jurassic, and Cretaceous sedimentary rocks. The beds dip to the east. The streams in the area are underlain by Quaternary alluvium.

The existing supply of water for Fort Defiance is obtained from an infiltration gallery in the alluvial fill of Bonito Creek. Scouring in the bed of the creek has lowered the level of the fill and decreased the productivity of the gallery. The possibility was considered of constructing a low dam, which would be keyed into the rocks underlying the fill. This dam would impound the underflow in the fill and increase the yield of the gallery, but the cost probably would be excessive.

The investigation showed that it would not be advisable to obtain water for Fort Defiance by drilling a well. The yield from a well probably would not exceed 25 gallons per minute, and the depth would have to be greater than 1,500 feet.

The most practicable method of procuring additional water would be to develop and utilize the flow from two artesian springs that issue from the lower member of the Cutler formation (Permian) in the area. The quality of the water from these springs is suitable for domestic use.

Bonito Spring, the larger of the two, occurs in the bed of Bonito Creek about a mile upstream from the infiltration gallery, in an area where the lower member of the Cutler formation is overlain by 10 feet of alluvial fill. If a caisson were constructed in the fill at the spring, it is estimated that about 200 gallons per minute could be withdrawn by gravity flow. Calculations based on measurements of the spring discharge indicated that as much as 500 gallons per minute might be obtained if all the water from the spring could be collected into a caisson and pumped from an elevation 10 feet lower than the existing outlet of the spring.

Supai Spring, the smaller of the two, produces about 75 gallons per minute from the lower member of the Cutler formation in a wash tributary to Bonito Creek. Water from the spring could be collected into a pipe line and would flow by gravity to Fort Defiance.

Full use of the water from both springs would decrease the underflow of Bonito Creek and reduce the supply of ground water now available to the infiltration gallery. Development of the springs could be accomplished in three stages, depending on the amount of water needed by the community:

1. Construct a caisson at Bonito Spring and withdraw water by gravity flow. This would not seriously reduce the amount of water available at the infiltration gallery.
2. Withdraw water from Bonito Spring by pumping from the proposed caisson. This would reduce the amount of water available at the gallery.

3. Capture the entire flow of Supai Spring and pump from the proposed caisson at Bonito Spring. This would increase the total supply available, by reducing the amount of water now lost by evaporation from the stream bed, and by greatly reducing the underflow, part of which now passes the infiltration gallery.

INTRODUCTION

Late in January 1948 the Geological Survey was requested to investigate the possibilities of obtaining additional water supplies at several sites on the Navajo Indian Reservation. This request included an investigation of the water supply at Fort Defiance.

Location

Fort Defiance is located at the mouth of Bonito Canyon, near the confluence of Bonito Creek and Black Creek, in the east-central part of Apache County, Arizona. The town lies on the eastern flank of the Defiance uplift at an elevation of about 6,850 feet. The settlement was established shortly after 1850, and has been continuously occupied since that time. In 1948, the population was estimated to be 1,200.

Summary of problem

The existing water supply consists of an infiltration gallery in the alluvial fill of Bonito Creek, about 1 mile upstream from Fort Defiance (see pl. 1). The gallery is reported to produce about 100 gallons per minute. The water flows by gravity to Fort Defiance, from where it is pumped to a 275,000-gallon storage tank on a hill northwest of the town.

Scouring in the bed of Bonito Creek during the past few years has caused a lowering of the water level in the infiltration gallery. The continued lowering of the water table has decreased the flow from the gallery so that the supply during the summer months is no longer adequate. The initial problem was to develop a supply of water which would be adequate to meet the needs of the community at all times. Later, a second problem was presented: To increase the supply of water to accomodate a proposed total population of about 3,000. The additional 1,800 people would be located at a school to be built on the east side of Black Creek, about 3 miles east of Fort Defiance (see pl. 1).

Assuming a daily rate of use of 150 gallons per person, a continuous supply of about 125 gallons per minute would be needed to support the present community of 1,200 people, and a continuous supply of about 315 gallons per minute would be needed for 3,000 people. If it is necessary to pump the needed water, and if it is desirable to confine the pumping to an 8-hour period each day, the rates of supply required would be 375 and 950 gallons per minute, respectively.

Three possible methods of obtaining additional water were suggested: (1) Place a low dam across Bonito Creek below the infiltration gallery, to raise the water table and increase the flow from the gallery; (2) drill a well in the valley of Black Creek; and (3) develop and utilize a spring in Bonito Creek about a mile upstream from the infiltration gallery.

Field work and acknowledgments

The work was done under the general supervision of S. F. Turner, District Engineer (Ground Water). Field work was done by S. C. Brown, geologist, and L. C. Halpenny, engineer, during parts of March, April, July, and August, 1948. The writers are indebted to C. B. Read, of the Geologic Division; J. D. Hem, of the Quality of Water Branch; and H. V. Peterson, of the Technical Coordination Branch, Water Resources Division. Mr. Read assisted in interpreting the stratigraphy of the region, and Mr. Hem made the quality-of-water interpretations. Mr. Peterson made a preliminary survey of the area.

GEOLOGY AND GROUND-WATER RESOURCES

Geologic formations and their water-bearing properties

The geologic section exposed in the Fort Defiance area is as follows:

QUATERNARY	Recent alluvium
TERTIARY (?)	Basalt
CRETACEOUS	Undifferentiated
JURASSIC	(Morrison formation (San Rafael group (Entrada sandstone (Carmel formation
JURASSIC (?)	Glen Canyon group, undivided
TRIASSIC	(Chinle formation (Shinarump conglomerate
PERMIAN	Cutler formation Upper member DeChelly sandstone member Lower member
PRE-CAMBRIAN	Quartzite

Plate 1 is a geologic map of the area and plate 2 is a geologic section showing the stratigraphic relations. The scale of the map is not sufficient to allow showing both the upper member and the DeChelly sandstone member of the Cutler formation as separate units along Bonito Creek, and therefore they are shown as a single unit.

Pre-Cambrian rocks

Approximately 100 feet of quartzite, of pre-Cambrian age, is exposed about 2 miles northwest of Fort Defiance. The quartzite is fine-to medium-grained, dark gray, and weathers into angular fragments. It does not produce water in the area.

There is evidence that the Fort Defiance area may be underlain by granite, as several wells along the Defiance uplift have encountered granite below the lower member of the Cutler formation. According to Darton,^{1/} a test well $6\frac{1}{2}$ miles northwest of Fort Defiance encountered granite at 114 feet. A well drilled approximately 30 miles northwest of Fort Defiance, near Nazlini Trading Post, encountered what was reported to be granite below the member at a depth of about 800 feet. It is reported that water flowed from this well, and that stock which drank the water died. No water samples are known to have been collected before the well was plugged.

Permian rocks

The lower member of the Cutler formation, of Permian age, lies unconformably upon the pre-Cambrian quartzite. Between 300 and 350 feet of the member is exposed in the area. It is composed of alternating beds of fine-grained sandstone, shaly sandstone, and shale. The exposed part of the member is dark reddish brown in color and is heavily jointed.

All the springs observed in the area issue from solution channels along joints in the lower member of the Cutler formation. Two prominent sets of joints, dipping almost vertically and striking N. 20° W. and N. 50° E., were observed in the spring areas. Water from rain and melting snow enters the member in its outcrop area and issues from the solution channels. The lower member of the Cutler formation is the source of Bonito Spring (pl. 1), which issues in the bed of Bonito Creek. The member is overlain by 10 feet of alluvial fill at the spring, and water from the formation is under sufficient artesian pressure to move upward through the fill to the surface. Supai Spring (pl. 1) issues from the lower member of the Cutler formation in the small wash that enters Bonito Creek from the west a few hundred feet north of the infiltration gallery. The member crops out in the bed of the wash at this locality, and the spring issues directly from solution channels along joints. At least four other springs are known to issue from the lower member of the Cutler formation within a few miles north of the Fort Defiance area. East of Bonito Creek the beds of the member dip underground, and at the school site they lie at too great a depth to be considered of value as an aquifer.

The DeChelly sandstone member of the Cutler formation is massive, highly cross bedded, fine- to coarse-grained, and light to medium red in color. The sandstone ranges from 100 to 150 feet in thickness, and is exposed in the lower part of the east wall of Bonito Canyon.

In other parts of the region this sandstone is generally a good aquifer, although near Fort Defiance the small outcrop area limits recharge. The sandstone probably lies at least 1,900 feet below the land surface at the proposed school site 3 miles east of Fort Defiance. It is doubtful whether the needed supply of water could be obtained from the DeChelly sandstone member at the school site, as the recharge area is limited and the water-bearing properties are unknown. Therefore, the cost of drilling a test well to the depth at which the member lies probably would not be warranted.

^{1/} Darton, N. H., A resume of Arizona geology: Univ. Arizona Bull. 119, p. 86, 1925.

The upper member of the Cutler formation lies with apparent conformity upon the DeChelly sandstone member. The exposure at Fort Defiance is in the same stratigraphic position as the Hoskinnini tongue of the Cutler formation of Monument Valley, Utah,^{2/} and the Moenkopi formation of the Black Mesa Basin of Arizona. In Bonito Canyon the upper member consists of 150 to 200 feet of alternating beds of massive, slightly cross bedded sandstone with depositional breaks at intervals of approximately 25 feet. The sandstone is fine- to coarse-grained, and the color ranges from light gray and buff to light red brown on the weathered surface. This member is overlain unconformably by the Shinarump conglomerate, of Triassic age. C. B. Read,^{3/} of the Geologic Division, has indicated that the lower 80 to 100 feet of what is described here as the upper member of the Cutler formation may be the equivalent of the Glorieta sandstone member of the San Andres formation of New Mexico, and that for the Fort Defiance area this 80 to 100 feet could be classified as the upper phase of the DeChelly sandstone member.

The water-bearing capacity of the upper member of the Cutler in the Fort Defiance area is not known. No wells in the area are known to produce water from the member. Furthermore, the exposures are high on the east wall of Bonito Canyon and present a small recharge area.

Triassic rocks

The Shinarump conglomerate, of Triassic age, lies unconformably upon the upper member of the Cutler formation and is overlain unconformably by the Chinle formation, also of Triassic age. The Shinarump conglomerate consists of about 30 feet of coarse-grained sandstone and cobble conglomerate. The cobbles are well rounded and are predominantly of quartzite and petrified wood.

The outcrop area of the Shinarump conglomerate occupies several square miles along the east flank of the Defiance uplift, thus presenting a good opportunity for recharge. In at least one place Black Creek flows over exposures of the formation, affording an opportunity for recharge during periods of stream flow. It is believed that this formation might be water bearing at the school site and that a well drilled into it might yield as much as 10 to 25 gallons per minute. The well would have to be at least 1,500 feet deep to reach the Shinarump conglomerate. The water probably would be under artesian pressure, but it is doubtful that the well would flow.

The Chinle formation, of Triassic age, lies unconformably upon the Shinarump conglomerate and is overlain with apparent conformity by the Glen Canyon group. The Chinle formation consists predominantly of variegated shales with occasional thin beds of sandstone and conglomerate. The conglomerate beds are composed of sandstone with quartz pebbles, some quartzite, and inclusions of red clay.

A limited supply of water might be obtained from some of the sandstone and conglomerate members of the Chinle formation. A series of seeps totaling about 25 gallons per minute issue from the formation along the unnamed wash south of Coal Mine Wash.

^{2/} Baker, Arthur A., Geology of the Monument Valley-Navajo Mountain region, San Juan County, Utah: U. S. Geological Survey Bull. 865 pp. 38-40, 1936.

^{3/} Read, C. B., Personal communication, Dec. 10, 1948.

Jurassic and Cretaceous rocks

The stratified rocks overlying the Chinle formation include the Glen Canyon group of Jurassic (?) age, the San Rafael group, and Morrison formation of Jurassic age, and the Dakota sandstone and Mancos shale of Cretaceous age. All these rocks crop out on the high ridge east of the school site and dip toward the east.

The rocks of the Glen Canyon group probably are water bearing east of the area studied. Several seeps were noted at the base of the Navajo sandstone of the Glen Canyon group, and a small part of the flow of Coal Mine Wash may be derived from seepage out of the Navajo sandstone. Any water that might be found in these rocks would be costly to develop and utilize.

Tertiary (?) and Quaternary rocks

Basalt of Tertiary (?) age is exposed near Black Creek in a hill known as Black Rock. The basalt does not yield water in this area.

About 50 feet of silt of Recent (Quaternary) age lies along the course of Bonito Creek. The creek has cut a channel through the silt and has redeposited about 10 to 15 feet of sand and boulders. The infiltration gallery supplying Fort Defiance has been constructed in the sand and boulder fill at the edge of the Creek.

Recent alluvium of unknown thickness, consisting of fine-grained sand and clay, is exposed along the course of Black Creek. There are a few dug wells in this alluvium north of the Fort Defiance area, but they are reported to produce water of very poor quality.

Structure

No faults were mapped in the Fort Defiance area, although definite evidence of a fault in the Chinle formation was observed about 3 miles northeast of the town. The fault could not be traced.

The beds in the Fort Defiance area, along the east flank of the uplift, dip 20° to 15° E. The strike of the beds ranges from N. 5° W. to N. 35° E.

SURFACE WATER

Bonito Creek is the only perennial stream in the area. It derives its water from rainfall and melting snow and from springs which maintain the low flow during the summer months. The flow of the creek is used for irrigation during part of the year. The creek was estimated to be flowing from 2 to 5 second-feet at various times during February and March 1948.

Black Creek, which has the largest drainage area of the streams in the region, derives its water from rainfall and melting snow on the Defiance uplift and in the Chuska Mountains. Flows of 5 to 50 second-feet were observed during the spring of 1948. Except for flood flows, the creek is dry during the summer months.

Intermittent flow was noted in Coal Mine Wash where the creek crossed successive hard-rock outcrops of the San Rafael group and the Glen Canyon group. This water disappeared into the alluvial fill of the stream a few feet downstream from each outcrop.

A small flow was observed along the unnamed wash south of Coal Mine Wash. A ledge of sandstone of the Chinle formation crops out beneath the bridge on the Window Rock road, and at that point the flow was estimated to be 25 gallons per minute on April 30, 1948. A few feet downstream from the bridge the water disappeared into the alluvial fill.

QUALITY OF WATER

By J. D. Hem

Table 1 lists analyses of 13 samples of water collected in the Fort Defiance area. All the waters are moderately hard, but with one exception they contain only moderate amounts of dissolved matter. On the basis of their dissolved solids all but one of the waters would be considered satisfactory for domestic use. The water from the seep in the unnamed wash south of Coal Mine Wash contains excessive amounts of sodium and sulfate, probably derived from the Chinle formation.

The analyses of water samples from Bonito and Supai springs indicate the chemical character of water in the lower member of the Cutler formation in this area. The water from Supai Spring contains mostly calcium and bicarbonate. Water from Bonito Spring is considerably higher in dissolved solids concentration than water from Supai Spring. The difference is largely in sodium, sulfate, and chloride. The differences in concentration at the two spring locations may be the result of one of the waters passing through a portion of the member that contains larger amounts of soluble matter.

Samples taken from the infiltration gallery that supplies Fort Defiance show a considerably lower chloride concentration than the samples from Bonito Spring. Although some change in the composition of the underflow of Bonito Creek probably occurs during the year, the analyses indicate that, at the time the samples were collected, a considerable part of the underflow at the infiltration gallery was derived from sources other than Bonito Creek.

WATER SUPPLIES

Present Fort Defiance supply

The infiltration gallery on Bonito Creek is parallel to the creek, at the base of a cliff of silty alluvial fill about 40 feet high and about 50 feet west of the stream channel. The gallery consists of three concrete caissons, each about 10 feet square and about 12 feet deep. The caissons are connected by a tunnel, from which the water flows by gravity through a 5-inch line to Fort Defiance. About 1947, in an effort to increase the diminishing discharge from the gallery, an 8-inch diameter hole was drilled in the center of each caisson. These drill holes passed through 6 feet of fill in one of the caissons and through 4 feet of fill in the other two caissons. All three holes were drilled 4 feet into the underlying lower member of the Cutler formation. After the holes were drilled,

the total depth of one caisson was 22 feet and the total depth of each of the other two was 20 feet. At the same time, one of the shallower caissons was disconnected from the flow line, so that at the time this report was written only two of the caissons were supplying water for Fort Defiance.

It has been reported that the gallery was constructed many years ago in what was then a seepage area. However, no evidence of a seep or of a spring in the underlying lower member of the Cutler formation was found there during the investigation.

The source of the water obtained from the infiltration gallery is believed to be underflow of Bonito Creek. The underflow is produced by infiltration from surface flow originating in the drainage area upstream from the springs, and from the discharge of Bonito and Supai springs. During periods in which no runoff occurs, the underflow is derived from the discharge of the springs.

Bonito Spring

Bonito Spring issues from the bed of Bonito Creek about a mile upstream from the infiltration gallery. The water issues under artesian pressure from solution channels along joints in the lower member of the Cutler formation and flows upward through the overlying fine sand. The spring furnishes a perennial supply to the stream. Part of the flow of the stream is utilized for irrigation by diversion into a canal about three quarters of a mile upstream from Fort Defiance.

There is little or no underflow of the creek upstream from the spring, as the creek bed lies on the lower member of the Cutler formation. A small amount of water may move downstream past the spring through the fine silt on each side of the creek.

A detailed study of the spring was made during the investigation. Three sets of discharge measurements were made, and three sets of water samples were collected. Probes were made with an iron bar to determine the thickness of fill overlying the hard rocks of the lower member of the Cutler formation. The plane table survey was extended as far as the spring.

The discharge of the spring was 265 gallons per minute on March 27, 1948. Later, the stream cut deeper and lowered the outlet of the spring by 2 feet. This increased the discharge to 315 gallons per minute, measured on April 22, 1948. The discharge of the spring was remeasured in the summer in order to determine the minimum flow. The discharge was 250 gallons per minute on July 18, 1948, at which time the stream channel had refilled to the approximate level of March 27.

The discharge measurements showed that the flow of the spring was increased by 50 gallons per minute when the outlet was lowered by 2 feet. From these data, the approximate specific capacity of the spring was estimated to be 25 gallons per minute per foot of drawdown. The probes showed that the lower member of the Cutler formation lies about 10 feet below the top of the sand. If all the overburden of sand were removed, and if water were withdrawn at the top of the lower member of the Cutler formation, the discharge of the spring might increase to as much as 500

gallons per minute. Most of the additional water thus obtained would otherwise have moved downstream as underflow in the alluvial fill. The balance of the additional water would be obtained from the lower member of the Cutler formation, due to the increased drawdown at the spring opening. The increase in yield from the formation would be sustained only if the increased drawdown eventually caused an increase in recharge to the formation or a decrease in discharge from other springs.

Supai Spring

The spring issues from solution channels along joints in the lower member of the Cutler formation in the bed of the wash that enters Bonito Creek a few hundred feet north of the infiltration gallery (pl. 1). The measured discharge was 75 gallons per minute on August 24, 1948. Part of the flow of the spring seeps into the alluvium of the wash and is evaporated, and part contributes to the flow of Bonito Creek.

POSSIBILITIES FOR OBTAINING ADDITIONAL WATER

Present Fort Defiance supply

The only method of permanently increasing the discharge of the infiltration gallery would be to place a low dam across Bonito Creek about 100 feet downstream from the gallery. The dam should be keyed into the lower member of the Cutler formation, and the crest should be about 4 feet above the present level of the stream. The dam would eventually increase the depth of fill at the gallery by about 4 feet, and would make the discharge of the gallery less susceptible to seasonal fluctuations.

If adequate means could be devised to tie the dam into the 40-foot high silt walls of the stream channel, the dam would be relatively inexpensive. If the dam had to be long enough to extend across the entire canyon, the cost might be great.

Well near school site

The geologic field studies led to the following conclusions with respect to drilling a well near the school site in Black Creek Valley:

1. Of the underlying formations, the Shinarump conglomerate is most likely to be water bearing.
2. The depth at which the Shinarump conglomerate would be encountered would be greater than 1,500 feet.
3. It is unlikely that a yield of more than 25 gallons per minute could be obtained from the formation.
4. Drilling a well at the school site for a public supply is not recommended.

Bonito and Supai springs

It is believed that the most practicable method of obtaining additional water in the Fort Defiance area would be to increase the discharge of Bonito Spring. A method by which the spring could be partially developed would be to construct a caisson in the fill, sealing it to the lower member of the Cutler formation with concrete to keep sand from entering at the bottom. The water level in the proposed caisson could be lowered about 4 feet below the present level of the creek by constructing a pipe line through which water would flow by gravity to Fort Defiance. It is estimated that, if the water level were lowered 4 feet, about 200 gallons per minute could be obtained from the proposed caisson. The remainder of the water discharged from the lower member of the Cutler formation at the spring would enter the alluvial fill outside the caisson and would move down the creek as underflow. Withdrawal of 200 gallons per minute from the caisson probably would not reduce appreciably the amount recoverable at the infiltration gallery downstream, but would reduce the surface supply for irrigation.

It is not believed that one caisson would capture all the flow of Bonito Spring. However, if a caisson were constructed and if the water level in it were lowered almost to the bottom by pumping, a large part of the total flow of the spring could be captured. Under these conditions, the supply of water at the infiltration gallery would be reduced, because the underflow of the creek would be less.

The water from Supai Spring now seeps into the fill of the wash and contributes to the underflow of Bonito Creek. The flow of Supai Spring could be collected into a pipe line and would flow by gravity to Fort Defiance.

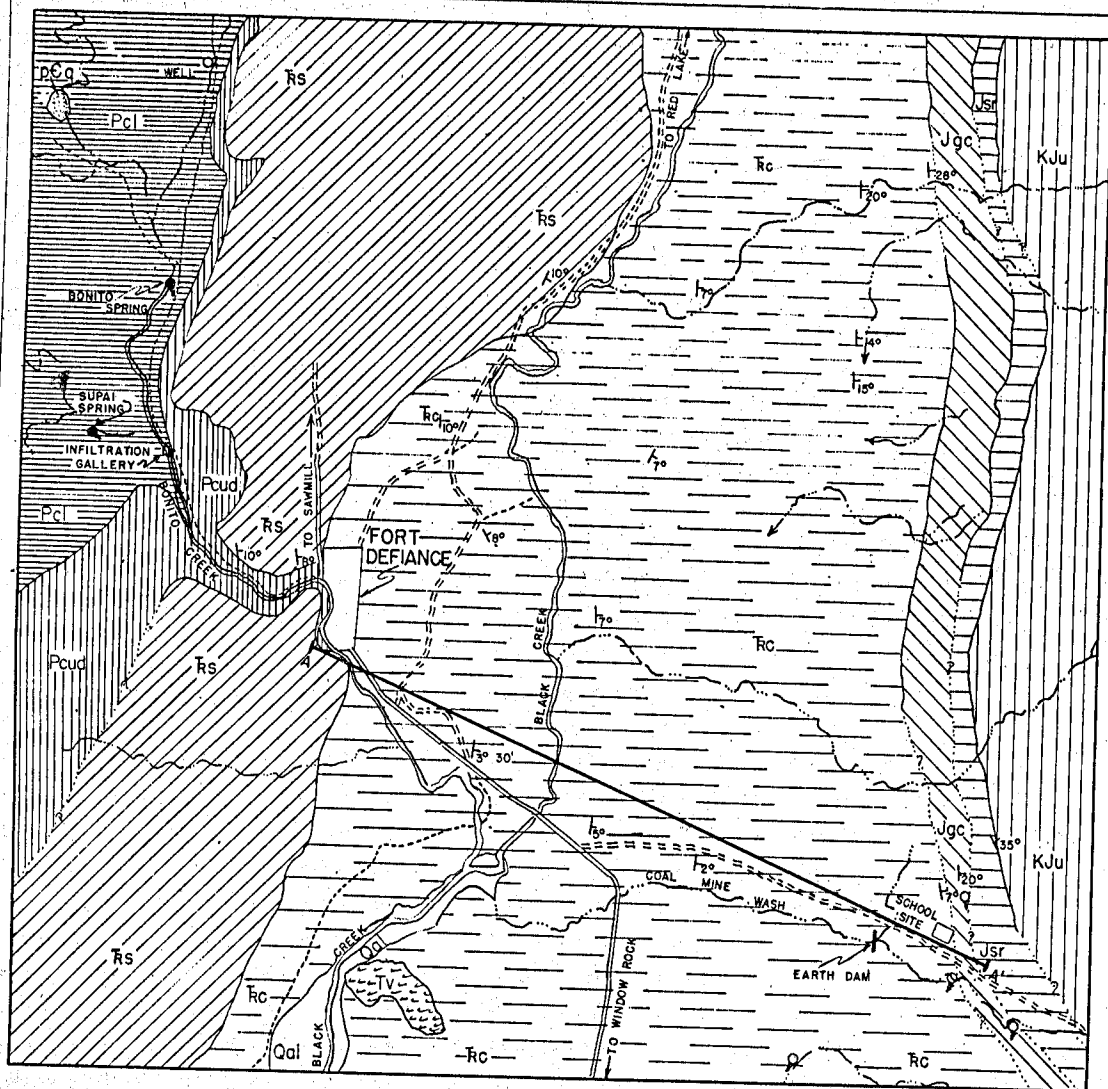
It is obvious that the supply of water at the infiltration gallery would be reduced considerably if the procedures outlined in both of the preceding paragraphs were followed. However, these two procedures would increase the total supply available by reducing that part of the underflow that now passes the infiltration gallery and the amount of water now lost by evaporation from the stream bed.

The two springs will produce sufficient water to supply the community of Fort Defiance and the proposed community of 1,800 at the school site, but it is doubtful if the springs could be developed sufficiently to supply both the domestic needs and the irrigation requirements. Supplemental water is available at Buell Park, which lies about 16 miles north of Fort Defiance. Water from this source would flow by gravity pipe line to the school site. Preliminary estimates indicate that about 250 gallons per minute of water of excellent quality is available at Buell Park. An investigation of that area is now in progress.

Table 1. Analyses of water from Fort Defiance area, Apache County, Arizona
Analyses by Geological Survey
(Parts per million except specific conductance)

Sample from	Date of collection, 1948	Temperature (°F)	Specific conductance (Micro-mhos at 25°C.)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na/K)	Bicarbonate (HCO ₃)	Sulfate (SO ₄)	Chloride (Cl)	Fluoride (F)	Nitrate (NO ₃)	Dissolved solids	Total hardness as CaCO ₃
Bonito Springs ^{a/}	Feb. 29	51	658	56	25	56	280	46	58	0.6	2.8	382	242
do.	Mar. 27	49	656	58	26	46	272	43	58	-	2.6	368	252
do.	Apr. 22	49	600	54	23	42	263	33	44	.4	3.0	331	229
do. ^{b/}	do.	48	601	-	-	-	264	-	43	-	-	-	-
do. ^{c/}	do.	49½	553	41	25	40	243	32	42	.4	.6	301	206
Bonito Creek ^{d/}	Mar. 27	59	354	42	17	15	206	23	9.0	-	1.8	209	175
do. ^{e/}	do.	-	410	46	22	9.7	212	28	16	-	1.6	228	206
Infiltration gallery	Feb. 29	51	471	56	23	18	273	23	14	.6	7.1	276	234
do.	Mar. 27	-	473	-	-	-	-	-	13	-	-	-	-
Seep ^{f/}	Apr. 30	55	1,910	130	46	265	287	785	25	1.2	.3	1,390	514
do. ^{g/}	Aug. 24	-	636	69	19	46	200	170	5	.7	1.0	409	250
Supai Spring ^{h/}	do.	63	384	51	17	8.3	230	16	6	.2	1.5	213	197
do. ^{i/}	do.	-	343	-	-	-	201	-	4	-	-	-	-

^{a/} Middle part of spring; ^{b/} Upstream part of spring; ^{c/} Downstream part of spring; ^{d/} Upstream from spring;
^{e/} Downstream from spring; ^{f/} In wash south of Coal Mine Wash (sample taken at road bridge); ^{g/} in Coal Mine Wash near school site; ^{h/} At start of flow; ^{i/} At mouth of wash.



UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
1949

PLATE I. MAP OF FORT DEFIANCE AND VICINITY, ARIZONA SHOWING GEOLOGY

EXPLANATION

MATERIAL

- Qal RECENT ALLUVIUM (QUATERNARY)
- T BASALT (TERTIARY ?)
- KJu MANGOS SHALE AND DAKOTA SANDSTONE (CRETACEOUS) AND MORRISON FORMATION (JURASSIC)
- Jsrf SAN RAFAEL GROUP (JURASSIC)
- Jgc GLEN CANYON GROUP (JURASSIC ?)
- Rc CHINLE FORMATION (TRIASSIC)
- Rs SHINARUMP CONGLOMERATE (TRIASSIC)
- Pcd CUTLER FORMATION { UPPER MEMBER AND DECHELLY SANDSTONE MEMBER LOWER MEMBER
- Pcl
- pCq QUARTZITE (PRE-CAMBRIAN)

WATER-BEARING PROPERTIES

- SHALLOW DUG WELLS PRODUCE LIMITED QUANTITIES. NON-WATER-BEARING IN AREA.
- SEEPS ISSUE ALONG JOINT PLANES BELOW WATER TABLE.
- SEEPS ISSUE ALONG JOINT PLANES BELOW WATER TABLE.
- SEEPS ISSUE ALONG JOINT PLANES BELOW WATER TABLE.
- ALONG WASHES, SEEPS AND SHALLOW DUG WELLS PRODUCE LIMITED AMOUNTS OF WATER. PROBABLY WATER BEARING BELOW WATER TABLE.
- NO WELLS OR SPRINGS KNOWN TO PRODUCE FROM THESE MEMBERS.
- SEVERAL SPRINGS ISSUE FROM JOINTS IN SANDSTONE.
- NON-WATER-BEARING IN AREA.

- 3° 30' T STRIKE AND DIP
- ?-? CONTACT NOT ACCURATELY LOCATED
- SPRING
- Q SEEP

- ===== GRADED ROAD
- ===== UNIMPROVED ROAD
- TRAIL
- LINE OF GEOLOGIC SECTION (PLATE 2)

MAP BASED ON PLANE-TABLE SURVEY AND ON AERIAL PHOTOGRAPHS.
GEOLOGY BY S. G. BROWN, PLANE-TABLE SURVEY BY L. C. HALPENNY.

SCALE: 0 1 2 MILES

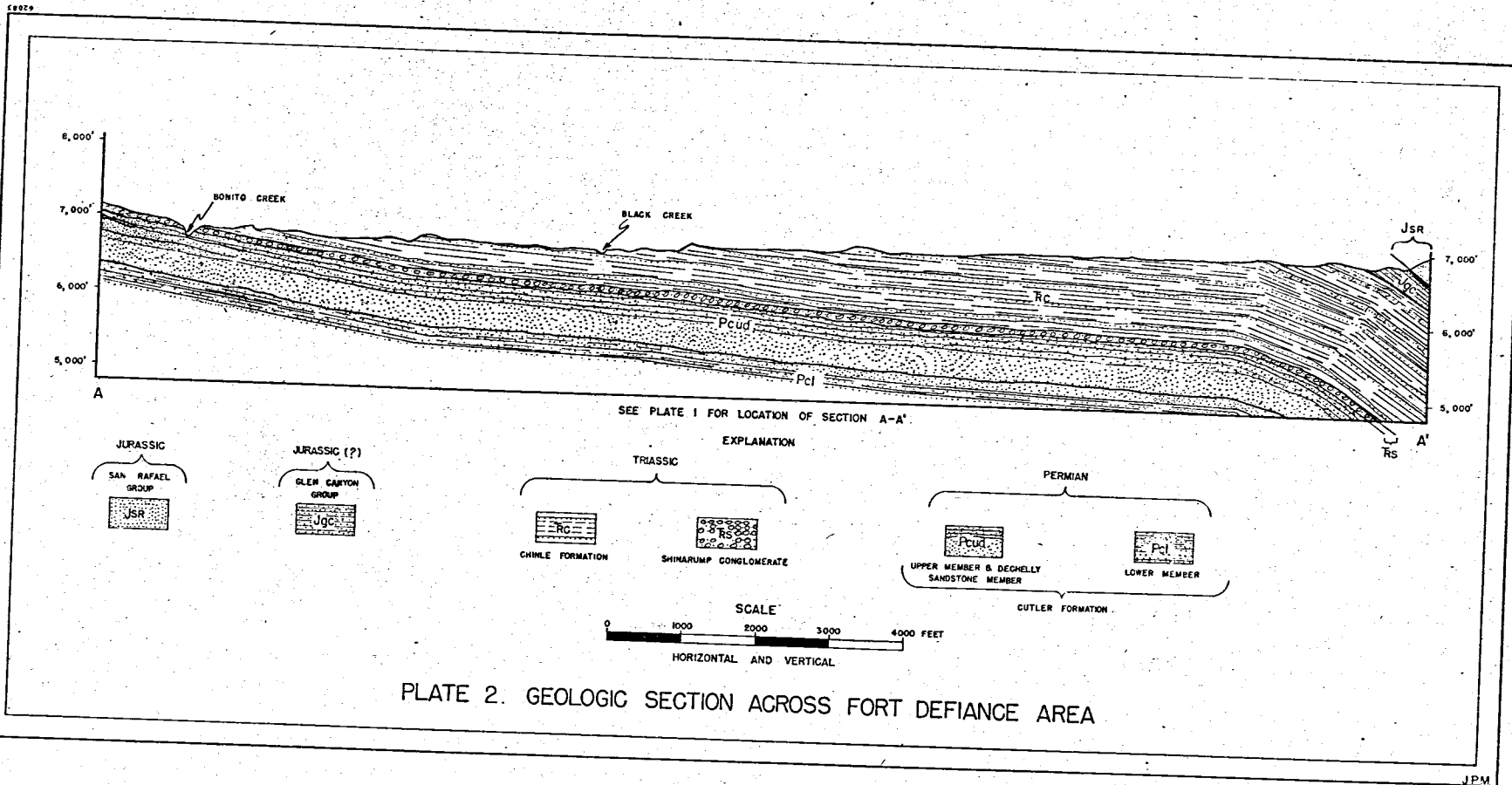


PLATE 2. GEOLOGIC SECTION ACROSS FORT DEFIANCE AREA